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The Nature and Role of Attentional Resources in Controlled and Automatic Detection: A Final Report

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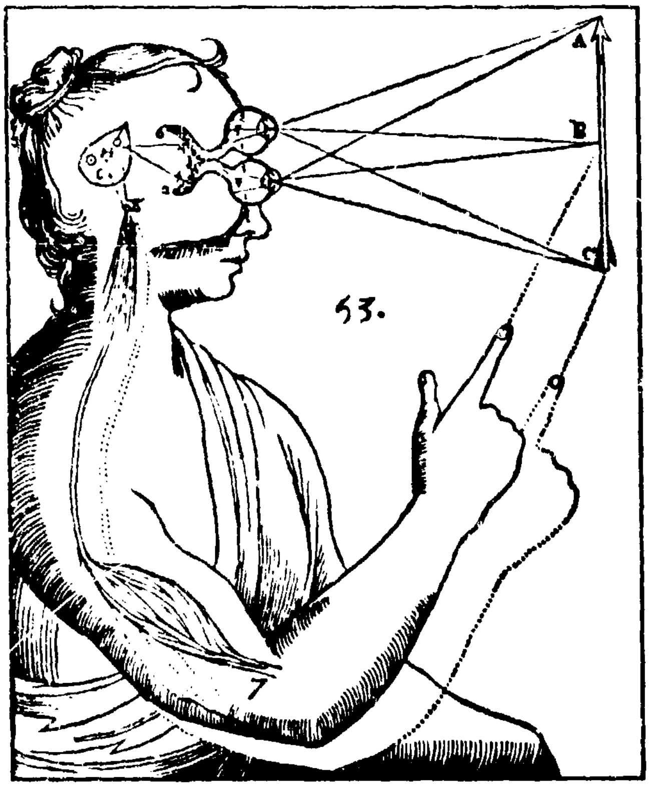

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In addition to the spatial attention system, automatic detection requires use of comparison processes in working memory. Even partial attention to a secondary task delays the occurrence of the overt detection response suggesting that decisions on two concurrent tasks must occur in working memory in a serial fashion. Converging evidence from an event-related potential (ERP) experiment supports this conclusion. The magnitude of the P300 component of the ERP, which indexes decision making in working memory, was found to be similar for both controlled and automatic detection tasks.

Extensive training in detection tasks does not result in a skill that is "resource-free." The main function of consistent-mapping training may be to refine the triggering conditions for the application of limited perceptual resources.

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The Nature and Role of Attentional Resources in Controlled and Automatic Detection: A Final Report

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Abstract

A series of experiments examined the role of attentional resources in automatic detection by pairing a consistently mapped visual target detection task with a series of concurrent discrimination tasks. The pattern of inter-task interference suggested that automatic detection requires two distinct kinds of resources.

The occurrence of automatic visual targets produces a shift of the visual spatial attention system to the area of the target. This reallocation of attention enhances the visual representation of the target and any other forms within the attentional field. Subjects do not have complete control of this process since automatic targets disrupt performance on the concurrent task even when subjects are instructed to ignore them.

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Extensive training in detection tasks does not result in a skill that is "resource-free." The main function of consistent-mapping training may be to refine the triggering conditions for the application of limited perceptual resources.

Performance of perceptual-motor and cognitive skills improves with practice. Performance becomes faster, more accurate, and most strikingly, apparently effortless. The ability to "automatize" skills is a key ingredient of successful performance in situations requiring the observer to "time-share" several tasks. Indeed, massive practice in a skill can produce truly remarkable time-sharing performances. Both skilled typists and pionists have been able to combine their skills with an auditory shadowing task without mutual interference (Shaffer, 1975; Allport, Antonis, & Reynolds, 1972). These observations suggest that training may reduce the attention required by a task so that it can be combined with other attention-demanding skills without exceeding the subject's total processing resources. Such a view has several practical implications, the most important being that intensive training may allow personnel to meet increased work-loads without any degradation in performance.

Work conducted under the previous contract (N00014-78-C-0762) was designed to explore the resource requirements of a highly trained skill; the principal question being: are there "hidden" resource costs associated with an automatic skill and, if so, what in the nature of such resources?

Dual-Task Experiments in Automatic Detection

The skill we chose to investigate was visual target detection, primarily because the training conditions underlying the development of this skill have been thoroughly explored (Schneider & Shiffrin, 1977). Schneider and Shiffrin (1977) showed that allowing a subject to search for the same set of targets in a constant set of distractors, a training regimen known as consistent mapping or CM, produced search times that were relatively

independent of processing load, defined as the product of the number of display characters and number of potential targets. In contrast, when targets and distractors periodically exchanged roles, a training schedule which is varied mapping or VM, search time was a linear function of processing load with a slope of about 40 msec per character.

An extensive series of experiments led Schneider and Shiffrin to characterize the processing modes produced by these two training schedules as being qualitatively different. VM training leads to controlled processing which is slow, serial, under subject control, and makes extensive use of short-term memory. CM training leads to automatic processing which is fast, parallel, inflexible, and does not require short-term memory.

If we assume that short-term memory is the primary source of capacity limitations in information processing (Shiffrin, 1978), then CM training in target detection should allow the observer to combine this skill with other tasks without mutual interference. We tested this prediction by combining a CM search task with a variety of concurrent discrimination tasks. The principal question was: To what extent is the speed and accuracy of automatic detection independent of demands made by other competing cognitive tasks? The role of spatial attention in automatic detection was of particular interest. Both Neisser (1967) and Schneider and Shiffrin (1977) reported that extensive training in visual search resulted in the target "popping out of the page." This pop-out phenomenon may explain why subject's performance on a controlled search task is impaired by the presence of a to-be-ignored CM target.

Our goal was to develop objective measures of the spatial allocation of attention and to use these measures to determine whether the ability of CM targets to trigger a shift of spatial attention plays a functional role

in detection. Figure 1 shows the general procedure. Subjects search for the presence of digits in a display of letters and indicate their decision with a speeded yes/no response. In addition, they must discriminate which of four light points located in the vicinity of the display characters is briefly extinguished.

The relative amount of attention to be paid to each task is varied across different blocks. For example, the subject is instructed to pay 90%/10% attention to the search and flicker tasks respectively. The pairs of performance values generated under different attention instructions produces a performance-operating-characteristic or POC (Sperling & Melchner, 1978; Navon & Gopher, 1979). When performance in dual-task conditions is equivalent to that obtained in single task conditions (100% attention devoted to the task) then the POC will appear to be a rectangle with one corner located at the single task performance levels. Increasing interference between tasks is reflected in POC's "below" this independence point.

Four major results were reported (Technical Report 8101) with this methodology. First, the POC was below the independence point indicating that the search task and flicker task were in competition for a limited resource and that subjects could control the allocation of this resource. Second, subjects detected automatic targets more often when they occurred adjacent to the flicker than when they occurred in nonadjacent positions (spatial adjacency effect). Third, subject's performance on the flicker task was impaired in the presence of an automatic target even when subjects were attempting to devote 100% attention to the flicker task (the "intrusion effect"). Fourth, even partial attention to the flicker task produced a large delay in the latency of the search response.

These results suggest that partial activation of the long-term memory mode representing the automatic target produces a shift of attention to the targets spatial area. This allocation of attention further increases the activation level producing a higher probability of detection. Following the formation of a data representation for the visual information, a procedure in short-term memory maps the occurrence of a target into an appropriate response. Dual task interference occurs on two levels. First, since spatial attention is a shareable resource (Navon & Gopher, 1979) only when visual information for each task falls in the same attentional field (Technical Report #8002), nonadjacent visual information will produce a trade-off in activation levels.

Second, because short-term memory is of limited capacity, it is unable to accommodate productions required to discriminate information for each task as well as to produce the required motor output for the search task. In dual-task conditions, this latter production has to be read into short-term memory following decisions on each task producing a delayed response.

This position makes two predictions. First, trade-off between CM detection accuracy and another concurrent discrimination should depend critically on the degree to which the two tasks allow for a sharing of spatial attention. Second, the delay in the CM detection response should be relatively independent of the nature of the concurrent task since all discriminations, even those involving different modalities, depend on procedures in a single amodal short-term memory.

The first prediction was tested with the procedure shown in Figure 2. Here, the concurrent task combined with the CM detection task occurs at the center of the display. Spatial attention can be either focused on the

center or distributed in the periphery allowing for little sharing between tasks. Large trade-offs in performance accuracy were obtained with this procedure and the intrusive effects of automatic targets were eliminated. The delay in the CM detection response was similar to that obtained with the flicker task.

The triggering of the spatial attention system by automatic targets was confirmed in a third experiment employing the procedure shown in Figure 3. The orientation of the U-shaped figure was easier to discriminate when it occurred adjacent to the CM target than when it appeared in other display locations. Once again, this demonstrates that discrimination of visual forms depends on spatial attention and that dual-task performance is aided by allowing spatial attention to be shared.

These results show quite clearly that spatial attention plays a functional role in the skill of automatic detection. CM targets trigger a shift of spatial attention to their display area, improving their own data representation as well as that of other nearby forms. These data also pose a puzzle. If CM targets are processed deeply enough to trigger a shift of attention to their area, why are further resources required for detection? This is really a question of the role played by spatial attention in form discrimination. Treisman and Gelade (1980) have recently proposed a role for visual attention that may clarify this puzzle. They suggest that the visual world outside the focus of attention consists of a set of unrelated features such as color, shape, etc. It is only within the focus of attention that feature sets are integrated into objects. A prediction of this theory is that features from different locations outside the focus of attention can combine to produce "illusory objects," a prediction confirmed

by Treisman and Gelade. They also reported that extensive training in looking for targets defined by feature conjunctions (e.g., "a green H") did not eliminate the need for attention.

It may be that in our experiments, spatial attention was allocated to the position of the CM target in order to verify that features present in that location were in fact a conjunction representing a CM target and not produced by illusory conjunctions of distractor features. This suggests that illusory conjunctions and therefore false alarms should increase in the CM detection task when attentional shifts are prevented. This is exactly what occurred with the procedure shown in Figure 2. False alarm rates in this experiment were 3 to 4 times those obtained with the other two procedures (Figures 1 and 3). Evidently, when subjects were focused on the center of the display, they suffered a large number of illusory conjunctions of letter features that looked like digits. This hypothesis should be examined directly, however, by varying the nature of the distractor letters in terms of their feature overlap with CM targets.

Mixed Modality Time-Sharing

Although CM detection accuracy depended critically on the nature of the concurrent task in dual-task situations, the delay of the CM response was relatively invariant across tasks. If the response delay does, in fact, represent a competition for an amodal short-term memory then it should be obtained even when a visual detection task is combined with an auditory discrimination task. To test this prediction, we combined a visual CM detection task with an auditory tone discrimination task and a visual orientation symbol task similar to the one shown in Figure 3, in alternating sessions. Table 1 shows how performance on each of these tasks depended

on the presence or absence of the CM target digit across different attention conditions.

Table 1

d' on Concurrent Task for Trials on Which the CM Target is Present or Absent

		Percent Attention Allocated to Visual or Auditory Task			
		10	50	90	100
Visual Task	Present	.85	.89	.96	1.43
	Absent	1.20	1.40	1.48	1.54
Auditory Task	Present	.85	.98	.91	1.05
	Absent	.80	.89	.93	1.10

The most striking result in this table is the robust intrusion effect when both tasks are in the same modality and the complete absence of this effect for mixed modalities. This verifies our contention that the intrusion effect represents a call by the CM target for a modality specific resource.

Table 2 shows CM response latency as a function of the modality of the concurrent task across different attention conditions. These data show a delay of response in dual-task conditions, independent of the modality of the concurrent task. This experiment provides a striking confirmation of the separate resource pools that play a role in automatic detection. Both a modality specific resource of spatial attention as well as an amodal resource in working memory are involved in different aspects of highly skilled detection and response.

Table 2

CM Search Reaction Time (msec) as a Function of the

Modality of the Concurrent Task

	Percent Attention Devoted to Search Task			
	100	90	50	10
Visual	700	937	975	1064
Auditory	700	922	941	1004

Event-Related Potentials in Automatic and Controlled Detection

The delay of the CM detection response in dual-task conditions could be due to a delay in just the motor response or a delay in the actual detection decision. One way to measure decision time independent of response time is to measure the latency of the P300 component of the event-related potential (ERP). The P300 component appears to index human decision making in a variety of detection and recognition tasks (Donchin, Ritter, & McCallum, 1978) and appears to be separable from the timing of the overt response. It would be of interest to measure the latency of the P300 component elicited by CM target detection and determine if it is delayed in dual-task conditions.

As a preliminary to this dual-task experiment, we measured ERPs elicited by targets in both CM and VM training schedules. This experiment can provide converging evidence for our supposition that automatic detection requires short-term or working memory. Donchin and his colleagues in a series of clever experiments (Israel, Chesney, Wickens, & Donchin, 1980;

Israel, Wickens, Chesney, & Donchin, 1980) have shown that P300 amplitude is a sensitive index of the resources allocated to a task. If CM detection requires a smaller resource investment than VM detection, then CM targets should produce smaller P300 components. In Technical Report #8102 we reported that P300 amplitudes for these two tasks are quite comparable.

Comparing Controlled and Automatic Detection Resource Costs

Although our dual-task experiments show quite clearly that CM detection requires attention, it might be argued that any attentional involvement is less than would be found for VM detection. Two experiments have directly compared CM and VM detection and found virtually identical dual-task trade-offs. The first (Report #8001) combined the flicker task of Figure 1 with CM and VM detection tasks. Presentation of the search arrays was supra-threshold making search reaction time the measure of interest. The results are simply stated: Both CM and VM RT was delayed in dual-task conditions and by the same amount. Similarly, flicker accuracy was impaired in dual-task conditions to the same extent by both types of detection. We recently confirmed these results in threshold conditions utilizing search accuracy as the measure.

Conclusions

In summary, a variety of dual-task experiments indicate that a highly trained and presumably automatic target detection task requires several different resources for effective performance. Features that match automatic targets trigger a shift of attention to their display area so that focused attention can eliminate illusory conjunctions and verify the presence of an automatic target. Preventing these shifts results in a large decrease in detection accuracy.

A second resource involved in automatic detection consists of the comparison, decision, and response execution processes of working memory. These procedures must be accessed serially and are a potent source of inter-task interference, especially when speeded responses are required. We found that all tasks we have studied, regardless of their spatial nature or even their sensory modality, impose approximately the same delay on the execution of the CM response.

Perhaps the most surprising result of these dual-task experiments is that not only does CM detection require resources but to about the same extent as VM detection as indicated by equivalent dual-task trade-offs. Is it possible that, in general, both controlled and automatic tasks have the same resource requirements? If so, what is the advantage of extensive training in time-sharing situations?

First, it should be recognized that our experiments represent rather special circumstance. In particular, CM detection accuracy only suffers when the concurrent task is one which offers simultaneous competition for the spatial attention system. Other experiments (Schneider & Fisk, 1980) in which there is no competition for a spatial attention system do not show dual-task trade-offs in accuracy. This finding is in keeping with results reported by Kahneman (1981) that even reading of highly overlearned words is impaired by competing visual inputs. The spatial attention system evidently plays a similar role in both CM and VM detection tasks.

The second restriction on our results is that all tasks were chosen to be relatively light in their demands on short-term memory. The fact that to-be-ignored CM targets can intrude on other controlled search processes indicates that rehearsal of CM target set is not required to keep their

long-term memory (LTM) nodes in an active state. Active rehearsal of LTM nodes does, however, play a significant role in VM detection, as shown by Fisk and Schneider (1981). Preventing rehearsal of the memory set impairs VM search while having little or no effect on CM search accuracy. CM detection latency, however, should, according to our analysis, show a deleterious effect of short-term memory load.

Anderson (1980) offers a useful perspective on the development of skills. He points out that initially a skill is represented in a declarative fashion and can usually be verbalized. Continued practice results in the skill becoming represented as procedures. If a skill initially consists of several different procedures, continued practice may allow these procedures to become "compiled" into one procedure which, once initiated by appropriate triggering conditions, may be executed without the involvement of attention.

Our time-sharing experiments make it clear that this completion stage never occurred for the search task. The mapping of a decision onto a motor response remained a separate procedure throughout training. This procedure had to be activated after the discrimination procedure in dual-task conditions producing a delayed response.

It is possible that massive training in motor skills does result in a complete compilation of the several procedures that initially make up the skill. Skilled typists, for example, receive large amounts of consistent mapping training in pairing a particular keypress with a particular symbol. Even here, however, it seems likely that motor output productions remain separate from other procedures. The typist does not "automatically" type when presented with visual material but must maintain an intention to do so (Schaeffer, 1976). Further, varying amounts of effort may be invested in

the typing process to reflect different speed pressures. This control that is maintained over an automatic skill may well reveal itself in dual-task experiments of the type discussed in this paper. The role of attention in continuous, highly practiced skills remains an important direction for future research.

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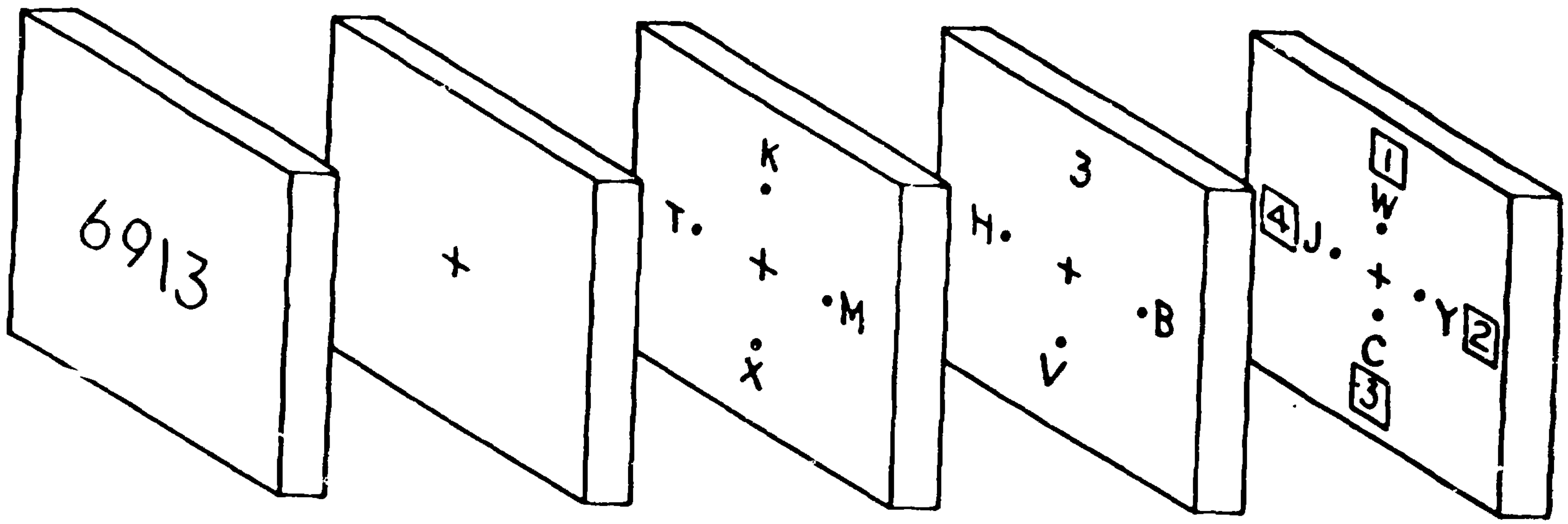

Figure 1: Sequence of events occurring on each trial of Experiment 1. Following presentation of the memory set the subject viewed three arrays: a premask, a target array, and a postmask. In dual task conditions subjects were required to determine whether a digit was present and which of four light points was briefly extinguished.

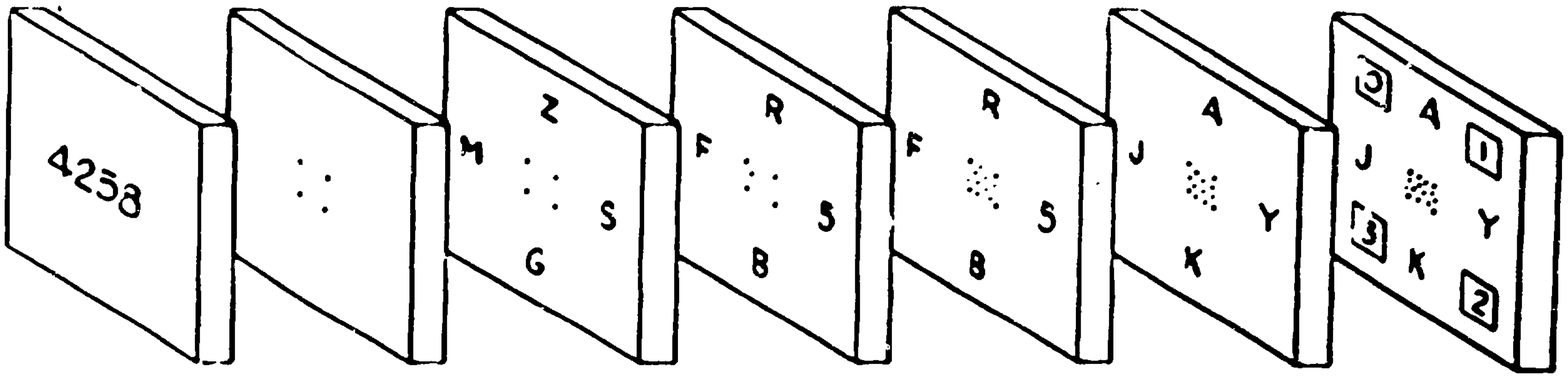

Figure 2: Sequence of events occurring on each trial of Experiment 2. The subject was required to determine whether a digit was present and to judge the direction of displacement of a centrally located dot. The occurrence of the dot was followed by a random field of masking dots.

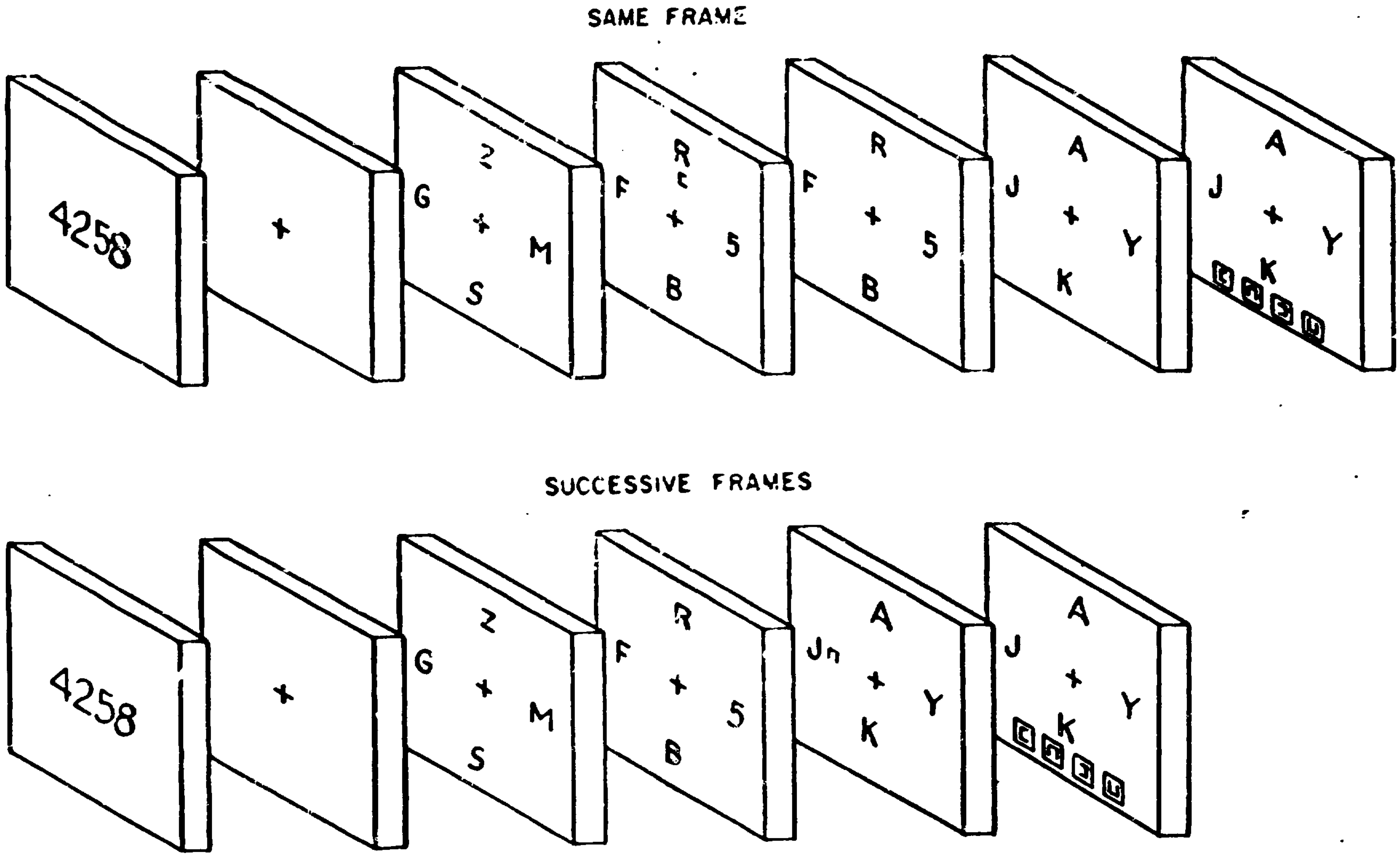

Figure 3: Sequence of events occurring on each of two kinds of traisl in Experiment 3. In the "same frame" condition, the subject was required to determine whether a digit was present as well as to judge the orientation of a simultaneously presented U-shaped figure. In the "successive frame" condition, the U-shaped figure occurred with the onset of the postmasks.

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